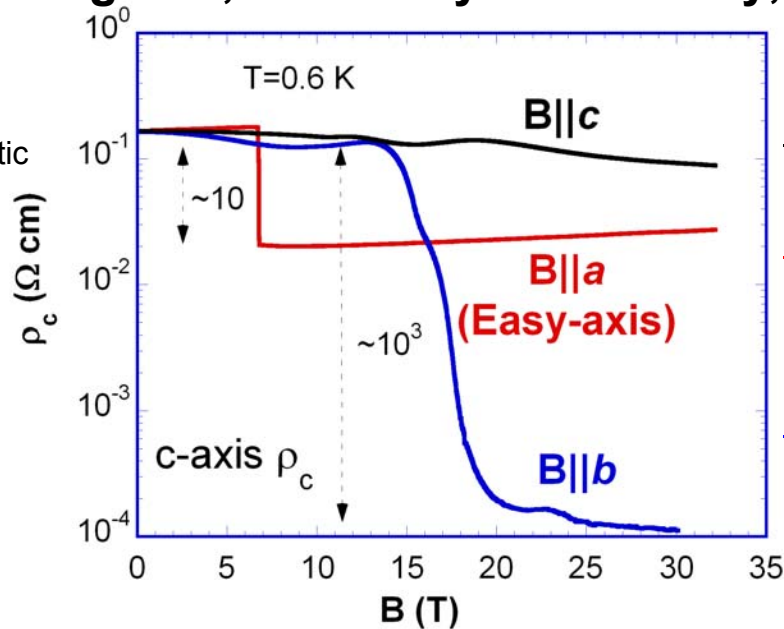


Orbital Physics: Metal-insulator Transition, Quantum Oscillations and Colossal Magnetoresistance in Ruthenate

Gang Cao, University of Kentucky, [DMR-0240813](#)

Fig.1 Electrical resistivity ρ_c as a function of magnetic field B for three crystallographic axes. Note that the a -axis is the magnetically easy-axis where magnetic spins are almost fully polarized at $B > 6$ T.



B||c: Quantum oscillations occurs in a nonmetallic state

B||a: More than 85% spin polarization can at most lower ρ by one order of magnitude

B||b: ρ_c drops by three orders of magnitude when the spin-polarized state is removed, which leads to melting of orbital ordering favorable for electron hopping

The bilayered $\text{Ca}_3\text{Ru}_2\text{O}_7$ features a metal-insulator transition, quantum oscillations and colossal magnetoresistance. The novelty of this system is that all these physical phenomena happen in such a way that conventional physics seems to be violated: (1) the colossal magnetoresistivity or drastic reduction in resistivity is achieved by demolishing a spin-polarized state where spin scattering is minimum. This is striking in that the spin-polarization, which is a fundamental driving force for all other magnetoresistive systems, is detrimental to the colossal magnetoresistance in this 4d-electron based system; (2) quantum oscillations or quantizations of electron orbits, which are a trademark of a good metal, occur in the nonmetallic state. It has become increasingly clear that in the ruthenates the orbital degrees of freedom play a fundamental role and that the novel phenomena are driven by the coupling of the orbits to the spin (spin-orbit interaction) and to the lattice (Jahn-Teller effect). (*Invited paper to be published in New Journal of Physics*)

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Education

Four graduate students have been involved in single crystal synthesis, characterization and high magnetic field measurements related with this and other projects. Of them, 2.5 graduate students have been supported by this grant. Out of 15 publications supported by this grant, 10 are co-authored by these students. Most of papers are published in Physical Review B.

These students have been trained with an emphasis on both new materials developments and characterization, a training that has been historically ignored in the US universities.

These Ph.D. graduate students are Xiunu Lin, Shaline Chakara, Esmat Elhami and Vino Durairaj. Of them, three are female students.

Impacts

The novel phenomena such as the quantum oscillations coexisting with the nonmetallic state and the colossal magnetoresistance achieved via demolishing a spin-polarized state defy conventional physics, highlighting an exotic ground state in this new class of materials. It is these novel phenomena that reflect new physics in the ruthenates fundamentally different from that governing all other materials.

The extensive and intensive research on novel electronic oxides in the last 2 decades has made it increasingly clear that the behavior of an assembly of interacting electrons will routinely surprise us with entirely unexpected phenomena. It is this potential for novelties that has driven our materials research efforts.

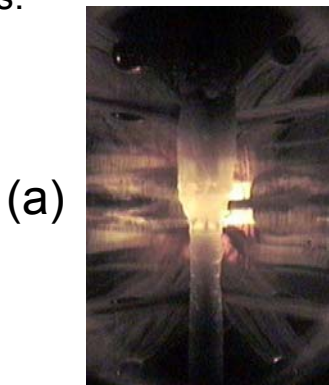


Fig.2 (a) Growing a single crystal using floating zone techniques; (b) Crystal of Calcium ruthenium oxide